JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

SCIENTIFIC CURIOSITY AND CRITICAL THINKING THROUGH SCIENTIFIC COLLABORATION: THE MODERATED MEDIATION ROLE OF SCIENTIFIC INQUIRY

Hande Baba Kaya,
Selahattin Akpınar,
Adem Çilek,
Gülten Türkan Gürer,
Öznur Akpınar,
Recep Mehmet Görünü,
Savaş Varlık

Abstract. *Although cognitive and social processes influencing students' scientific thinking skills have been extensively studied in recent years, the interplay between these processes remains insufficiently understood. This study examines the mediating role of research collaboration in the relationship between epistemic curiosity and critical thinking, as well as the moderating role of students' scientific inquiry skills in shaping these dynamics. Adopting a pragmatist paradigm, this research employs a mixed-methods research design, specifically an exploratory sequential design with a scale development component. The qualitative phase utilizes a case study design, incorporating in-depth interviews with teachers from science upper secondary in Mersin, Türkiye, to inform the theoretical framework for scale development. The quantitative phase applies a causal-comparative design, analyzing data from 371 teachers to test a moderated mediation model. The psychometric properties of the developed scale were rigorously assessed through content validity, construct validity, and reliability analyses, confirming its validity and reliability. Findings indicate that scientific collaboration significantly enhances the effect of scientific curiosity on critical thinking. However, the magnitude of this effect varies depending on students' scientific inquiry skills. Qualitative insights reveal that while teachers endorse student-centered approaches, they encounter challenges in implementing these methods effectively in classroom settings.*

Keywords: *critical thinking, scientific collaboration, scientific curiosity, scientific inquiry*

Hande Baba Kaya, Selahattin Akpınar
Düzce University, Türkiye
Adem Çilek,
Çankırı Karatekin University, Türkiye
Gülten Türkan Gürer
Gazi University, Türkiye
Öznur Akpınar
Karamanoğlu Mehmet Bey University, Türkiye
Recep Mehmet Görünü
Düzce University, Türkiye
Savaş Varlık
Ministry of National Education of the Republic of Türkiye, Türkiye

Introduction

Rather than being limited to individual reasoning, scientific thinking emerges through the interplay between cognition and social context. This view is also reflected in prior research, which highlights that it is not merely the product of individual cognitive processes (Antink-Meyer et al., 2023) but also a multi-layered field of interaction shaped by the social context (Cottrell, 2023). In this context, scientific collaboration emerges as a fundamental learning dynamic that nurtures students' curiosity (Fair, 2023) and deepens their critical thinking skills (Haber, 2020). On the other hand, scientific curiosity triggers the individual's orientation toward the unknown (Ribosa & Duran, 2022; Willis & Willis, 2020) and search for meaning (Bjerknes et al., 2023); critical thinking ensures that this process progresses in a systematic, questioning, and reflective manner (Fasko & Fair, 2020). However, the effective development of these two skills often depends on the interactive opportunities provided by the learning environment (Paul & Elder, 2020) and how students connect with these opportunities (Nicolopoulou et al., 2021). At this point, scientific inquiry processes can be evaluated not only as a pedagogical method (Books, 2023; Mahat & Kandel, 2023; Singh et al., 2023) but also as a moderated mediation mechanism in understanding this relationship. Building on this, the present research aimed to examine the impact of scientific collaboration on students' scientific curiosity and critical thinking tendencies, and sought to elucidate, at both conceptual and empirical levels, how scientific inquiry assumed a contextual mediation role in this interaction.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Literature Review

Not only cognitive skills (Dos Santos & Krause, 2017) but also social interaction dynamics (Dehghanzadeh et al., 2024) and affective characteristics (Chen et al., 2023) are decisive in students' orientation toward scientific thinking. In this context, scientific collaboration is a form of social interaction that transforms learning processes not only into sharing-based (Meyer et al., 2024) but also meaning-production-oriented ones (Feldman et al., 2024). At this point, Vygotsky's (1978) sociocultural theory emphasizes that the student's cognitive development is shaped through social interaction. Within the framework of this theory, scientific collaboration acts as a lever in realizing the student's cognitive potential (Abegglen et al., 2023). This is because collaborative learning processes enable not only the sharing of knowledge (Forbes, 2022) but also the comparison, structuring, and transformation of ways of thinking (Salmons, 2019). In this context, scientific curiosity and critical thinking emerge as the two fundamental mental tendencies in the student's approach to scientific knowledge (Bastianens et al., 2017; Hanscomb, 2023). Scientific curiosity encompasses the student's drive to explore the unknown, sensitivity to identifying gaps in understanding, and desire to discover (Dawson & Venville, 2022; Karwal et al., 2023); critical thinking is defined as the ability to question, justify, analyze, and reach consistent conclusions about information (Chatfield, 2022; Elder & Paul, 2020). The literature has frequently emphasized that these two tendencies reinforce each other in terms of cognitive flexibility and intellectual autonomy (Dave, 2024; Fury, 2024; Pu & Xu, 2023; Rousseau & van Gelder, 2024; Senent et al., 2021). However, the question of how the relationship between these two mental capacities is established highlights the importance of scientific collaboration as an explanatory variable. Collaboration diversifies cognitive stimuli among students (Muchie et al., 2024; Pu & Barnard, 2025) while also enabling the sharpening of curiosity through epistemic tensions and debates (Liu, 2020; Judijanto et al., 2025) and the strengthening of critical inquiry (Forman, 2020). However, it is evident that this relational structure is not one-dimensional but rather the product of a multi-layered mental activity. It is precisely at this point that scientific inquiry comes into play. Scientific inquiry refers to the student's active participation in the processes of systematically defining a scientific problem (Marco, 2025), developing hypotheses (Wulff, 2022), gathering evidence, and drawing conclusions (Bagdi et al., 2024). This process is not only a learning method but also provides a mental framework that shapes and guides the student's critical thinking (Bansal & Ramnarain, 2023; Concannon et al., 2020; Shearmur, 2020). In other words, scientific collaboration can only contribute significantly to critical thinking if students have effective inquiry practices (Book, 2024; Paavola & Shook, 2021). Therefore, the student's scientific inquiry capacity (Recker, 2021) should be considered a strategic variable that can determine the strength and direction of this relational line. Theoretically, this model overlaps with social cognition theory, constructivist learning theory, and the epistemic cognition approach. In particular, social cognitive theory argues that students' mental processes are shaped through interaction with others (Bandura, 1986), while the epistemic cognition approach (Greene et al., 2016) explains how students' beliefs about knowledge, the nature of knowledge, and the processes of knowing influence their critical thinking behaviors. The constructivist learning theory (De La Sienra, 2019) posits that students actively construct knowledge and that learning is shaped by experiences, social interactions, and prior knowledge. In this context, the theoretical axis of the research focuses on how students' higher-order cognitive tendencies, such as scientific curiosity and critical thinking, are shaped in a social context and through inquiry-based interaction (Madison, 2023; Pu & Xu, 2023). This approach makes it possible to understand not only individual but also collective cognitive capacities in today's complex information environments (Akpan et al., 2023; Nahar & Tayem, 2024). In light of all these theoretical perspectives, scientific curiosity, critical thinking, scientific inquiry, and scientific collaboration are interrelated concepts that are difficult to consider independently of one another. Scientific curiosity represents the internal motivation to learn and the desire to discover (Goodwin, 2020), while critical thinking provides a cognitive framework that enables this curiosity to be directed in a systematic and analytical manner (Kirk et al., 2023; Li, 2023). The relationship between these two tendencies is critical in terms of the student's intellectual depth and academic flexibility. At this point, scientific collaboration provides a social ground that encourages interaction among students, both keeping curiosity alive (Keengwe, 2022) and supporting the development of critical thinking (Fair, 2023). The theoretical proposition of the study is that scientific collaboration plays a mediating role between these two mental capacities. On the other hand, scientific inquiry is an important factor that determines the strength and direction of this association between scientific collaboration and critical thinking. Scientific inquiry, which refers to the student's active participation in scientific processes, is considered a regulatory variable that shapes this relationship. However, while research on the multi-layered cognitive and social processes that support students' scientific thinking capacities has increased in recent years (Butcher et al., 2023; Gai et al., 2022; Gyllenpalm et al., 2021; Hou et al., 2020; Kan et al., 2024; Kanyonga et al., 2024; Kirk et al., 2023; Lee & Haupt, 2020; Li et al., 2024; Liao

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

& Yuan, 2024; McPhee & Cox, 2024; Orona & Pritchard, 2021; Schwarz et al., 2023; Shahriary et al., 2020), it has remained limited in developing comprehensive models explaining how these processes interact with one another. In particular, the question of how higher-order cognitive tendencies such as scientific curiosity and critical thinking are shaped in social learning environments and which mediating and moderating variables are effective in these processes (Chaparro-Banegas et al., 2024; Kenett et al., 2023; Li, 2023; Oberman, 2023; Pollarolo et al., 2022; Reed et al., 2024; Whitworth, 2025) has remained an unresolved gap in the literature. Current research has mostly addressed these concepts in isolation (Anupam, 2022; Butcher et al., 2023; Cook & Wheeler, 2023; Fan et al., 2023; Kenett et al., 2023; Li & He, 2022; Liao & Yuan, 2024; Ninos, 2023; Oberman, 2023; Pu & Xu, 2023; Rogante et al., 2021; Rousseau & van Gelder, 2024; Senent et al., 2021; Shellito, 2020; Su et al., 2017; Suwono et al., 2021; Whitworth, 2025); it has not developed a holistic view of the dynamic relationship between the student's orientation toward scientific knowledge, critical inquiry skills, and social interaction practices (Varlık, 2024; Varlık et al., 2024). In this context, it is important to reveal how scientific collaboration functions not only as a pedagogical strategy (Chen et al., 2023; Li & He, 2022; Rogante et al., 2021) but also how it functions as a social foundation that transforms students' cognitive tendencies (Fan et al., 2023; Lee & Haupt, 2020). Based on this, the fundamental rationale of the research was based on the assumption that scientific collaboration could play a mediating role in the association between scientific curiosity and critical thinking, and that the strength of this role might vary depending on the student's scientific inquiry capacity. Within this framework, the objective of the study was to reveal the moderated mediation role of scientific inquiry in the association between scientific curiosity and critical thinking through scientific collaboration. Thus, the aim of this study was to develop a deeper understanding of both the function of social interaction-based learning environments and the multidimensional nature of scientific thinking. In line with this objective, the research provides a framework for understanding how students' scientific curiosity and critical thinking tendencies are shaped in social interaction and inquiry-based learning environments. In particular, it seeks to explain how processes such as scientific collaboration and scientific inquiry are related to these two mental capacities. The findings may provide clues as to the conditions under which collaborative and inquiry-based approaches can be more effective in teaching programs. In this respect, the research offers content that can contribute to the design of learning environments, the development of teaching strategies, and the support of students' higher-order thinking skills. Additionally, by more clearly highlighting the role of social interaction and active participation in the development of scientific thinking, it contributes to a more holistic approach to the interrelationships between these concepts in educational research.

Research Questions

1) How do science teachers perceive and define the concepts of scientific curiosity, critical thinking, scientific collaboration, and scientific inquiry?
2) Does scientific inquiry have a moderated mediation role in the association between scientific curiosity and critical thinking through scientific collaboration?

Research Methodology

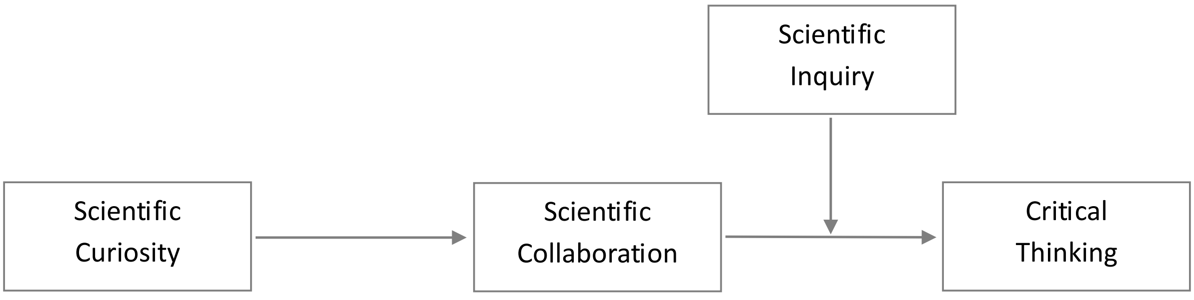
Design

The research is based on a pragmatic philosophical foundation that emphasizes the complementary power of both quantitative and qualitative approaches in knowledge production (Gunbayi & Sorm, 2020). In this regard, the research is structured within the framework of mixed-methods research (Mertens, 2023; Tashakkori et al., 2020) and adopts the scale development sub-design of the exploratory sequential design (Creswell & Guetterman, 2019; Fetters, 2020; Johnson & Christensen, 2020). The qualitative phase of the research was conducted according to the case study design, which aims to obtain contextual and in-depth data on students' scientific thinking processes (DeMarrais et al., 2024; Okoko et al., 2023). The findings obtained from this phase informed the scale development process and formed the basis for the quantitative dimension of the research. In the quantitative phase, causal comparative designs were used (Adams & McGuire, 2023; Blair et al., 2023; Crano et al., 2023) to test the relational structures between variables and analyze the developed model. This holistic approach ensured that the research was based on a more solid foundation at both the theoretical and practical levels. The theoretical design of the research is presented in Figure 1.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 1
Theoretical Model



When the theoretical model of the study is examined in Figure 1, the interactions between students' scientific thinking processes can be seen. According to the model, scientific curiosity stands out as an internal source of motivation for learning in students and paves the way for scientific collaboration. In this collaborative environment, students interact with each other through idea exchange and joint problem-solving processes. This process directly supports the development of critical thinking. The model also shows that scientific inquiry plays a moderated mediation role in this association. In other words, the inquiry activities that students carry out during scientific collaboration serve as a decisive factor in the transition to critical thinking.

This research was planned and conducted between September 1, 2024, and July 21, 2025. In addition, ethical committee approval for the research was obtained with the decision of the Düzce University Scientific Research and Publication Ethics Committee dated July 3, 2025, and numbered 351.

Sampling

The qualitative phase of the study was conducted with seven teachers working at science upper secondary in Mersin, Türkiye. Criteria sampling was used to select participants in accordance with qualitative research methods (Cry & Goodman, 2024). In this context, the criteria for selecting teachers for the sample were "working in the fields of physics, chemistry, or biology; having a master's or doctoral degree in at least two of the variables such as scientific curiosity, scientific collaboration, critical thinking, or scientific inquiry; or having at least one article published in an ESCI or Q4 indexed journal in these fields at the international level." ESCI, or Q4-indexed journal in these fields" were used as criteria for teacher selection. This ensured that teachers who could best contribute to illuminating the research problem were included in the study. The quantitative phase of the research was conducted on the teacher population in the central districts of Mersin Province: Akdeniz, Toroslar, and Yenişehir. According to information obtained from the Strategy Development Unit of the Mersin Provincial Directorate of National Education, the study population comprised 11,090 teachers, stratified by district as follows: "Akdeniz 3,781, Toroslar 3,797, Yenişehir 3,512," with each stratum exhibiting a homogeneous structure within itself. Considering a 5% margin of error and a 95% confidence level (Hiebert et al., 2023), it was calculated that at least 371 teachers needed to be included in the study. In this regard, simple random sampling was applied proportionally to the total number of teachers in each district using stratified sampling (Zou & Xu, 2023), and a total of 371 teachers were included in the study: 126 from Akdeniz, 127 from Toroslar, and 118 from Yenişehir. In this way, the representativeness of each stratum was sought to be ensured in the study.

Data Collection Tools

In the first phase of the research, semi-structured in-depth interviews were conducted with seven teachers working at a science upper secondary and who are experts in their field, with the aim of thoroughly examining the nature and dimensions of the concepts of "scientific curiosity, scientific collaboration, critical thinking, and scientific inquiry," which play an important role in science education. The qualitative data were systematically analyzed using a combination of thematic, descriptive, and content analysis techniques to provide a more comprehensive and nuanced understanding of the teachers' scientific thinking processes. Thematic analysis enabled the identification of recurring patterns and concepts across the data, descriptive analysis facilitated a detailed portrayal of participants' perspectives, and content analysis allowed for the quantification and systematic categorization of key

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

ideas. Initially, the data were coded and subsequently grouped under common themes, ensuring both depth and rigor in the analysis. As a result of the analyses, four main factors supporting the theoretical basis of the research were identified, and these factors formed the conceptual framework for the scale development process. Draft scale items were developed based on the qualitative findings, and these items were evaluated by a panel of field experts (five academics and three practitioners) in terms of content validity, language validity, and criterion validity. After making the necessary revisions based on expert opinions, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were applied to test the construct validity of the scale. Finally, McDonald's Omega (ω) reliability coefficients were calculated to determine the internal consistency level of each factor.

In the exploratory factor analysis conducted to measure the scientific curiosity factor, 11 items were initially used. However, three items with low factor loadings and related to other factors were removed, and the analysis was completed with eight items. To examine the construct validity of the scientific curiosity factor, the suitability of the data set for factor analysis was first evaluated. The Kaiser-Meyer-Olkin (KMO) sample adequacy coefficient was calculated as .834, and the Bartlett's sphericity test result was found to be significant (χ^2 = 1710.88; p < .001). These findings indicate that the data are suitable for factor analysis (Finch, 2019). In the examination conducted with principal component analysis, eight items with factor loadings ranging from .757 to .856 were grouped under a single factor, and this structure explained 73.715% of the total variance. The high KMO value, significant Bartlett test, and high variance explanation ratio indicate that the scale exhibits a strong factorial structure (Finch, 2019; Garson, 2023; Mindrila, 2017). Subsequently, confirmatory factor analysis (CFA) was conducted to validate the obtained factor structure. When examining the model fit indices, the following values were obtained: χ^2/df = 1.376, p > .001, CFI = .999, TLI = .996, RMSEA = .032, and SRMR = .019. These results support the model's good fit (Kline, 2023; Newsom, 2023). To examine construct validity in more detail, convergent validity and composite reliability values were calculated. The average variance explained (AVE) was found to be .722, and this value, being above 0.50, indicates that the factor's convergent validity is established (Crano et al., 2023; Zou & Xu, 2023). The composite reliability (CR) coefficient was calculated as .934, indicating that the factor has high internal consistency (Adams & McGuire, 2023; Hiebert et al., 2023). Finally, McDonald's Omega (ω) coefficient was calculated to assess the reliability of the factor and was found to be .856. This value supports the consistent structure of the scientific curiosity factor (Cipresson & Immekus, 2022). All of these findings are based on the 8-item *"I-1. My students ask 'why' and 'how' questions about the topics they learn in class; I-2. My students try to understand the process behind an experiment or topic rather than memorizing the results; I-3. My students are curious about and question the scientific mechanisms behind ordinary events; I-4. My students generate hypotheses such as "What if we tried another method?" and seek different solutions; I-5. My students conduct in-depth research by relating the information they learn to their daily lives; I-6. My students take an active role in laboratory applications and are eager to discuss the results; I-7. My students are not satisfied with scientific topics and seek additional information from other sources (books, videos, articles); I-8. My students do not give up trying, even if they make mistakes and recognize the value of learning in the process."* This demonstrates that the scientific curiosity factor is a valid and reliable measurement tool.

In the exploratory factor analysis conducted to measure the scientific collaboration factor, nine items were initially used. However, one item with a low factor loading value and related to other factors was removed, and the analysis was completed with eight items. To examine the construct validity of the scientific collaboration factor, the suitability of the data set for factor analysis was first evaluated. The Kaiser-Meyer-Olkin (KMO) sample adequacy coefficient was calculated as .865, and the Bartlett's sphericity test result was found to be significant (χ^2 = 1515.554; p < .001). These findings indicate that the data are suitable for factor analysis (Mindrila, 2017). In the examination conducted with principal component analysis, eight items with factor loadings ranging from .791 to .846 were grouped under a single factor, and this structure explained 70.037% of the total variance. The high KMO value, significant Bartlett test, and high variance explanation ratio indicate that the factor exhibits a strong factorial structure (Finch, 2019; Garson, 2023; Mindrila, 2017). Subsequently, confirmatory factor analysis (CFA) was conducted to validate the obtained factor structure. When examining the model fit indices, the following values were obtained: χ^2/df = 1.335, p > .001, CFI = .999, TLI = .996, RMSEA = .030, and SRMR = .013. These results support the model's good fit (Hoyle, 2023). To examine construct validity in more detail, convergent validity and composite reliability values were calculated. The average variance explained (AVE) was found to be .672, and this value, being above 0.50, indicates that the factor's convergent validity is established (Crano et al., 2023; Zou & Xu, 2023). The composite reliability (CR) coefficient was calculated as .938, indicating that the factor has high internal consistency (Adams & McGuire, 2023; Hiebert et al., 2023). Finally, McDonald's Omega (ω) coefficient was calculated to assess the reliability of the factor and was found to be .874. This value supports the consistent structure of the scientific collaboration factor (Luhanga & Harbaugh, 2021). All of these findings are based on the 8 items comprising *"I-1. My*

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

students actively exchange ideas in group work and value the opinions of others; I-2. My students successfully synthesize different perspectives by discussing a common scientific problem; I-3. My students contribute to a collective production process by sharing their knowledge and skills while working as a team; I-4. My students learn to draw on different fields by collaborating on interdisciplinary projects; I-5. My students defend their own ideas in group discussions while also demonstrating compromise skills; I-6. My students are aware that working together enriches scientific processes and embrace this approach; I-7. My students demonstrate a balanced ability to lead and be a team member when collaborating; I-8. My students value collective success over individual success and are motivated by achieving results as a team." This demonstrates that the scientific collaboration factor is a valid and reliable measurement tool.

In the exploratory factor analysis conducted to measure the critical thinking factor, nine items were initially used. However, two items with low factor loadings and related to other factors were removed, and the analysis was completed with seven items. To examine the construct validity of the critical thinking factor, the suitability of the data set for factor analysis was first evaluated. The Kaiser-Meyer-Olkin (KMO) sample adequacy coefficient was calculated as .848, and the Bartlett's sphericity test result was found to be significant ($\chi^2 = 1244.998$; $p < .001$). These findings indicate that the data are suitable for factor analysis (Garson, 2023). In the analysis conducted using principal component analysis, seven items with factor loadings ranging from .771 to .862 were grouped under a single factor, and this structure explained 70.629% of the total variance. The high KMO value, significant Bartlett test, and high variance explanation ratio indicate that the factor exhibits a strong factorial structure (Finch, 2019; Garson, 2023; Mindrila, 2017). Subsequently, confirmatory factor analysis (CFA) was conducted to validate the obtained factor structure. When examining the model fit indices, the following values were obtained: $\chi^2/df = 2.240$, $p > .001$, CFI = .997, TLI = .983, RMSEA = .058, and SRMR = .018. These results support the model's good fit (Verma & Verma, 2024). To examine construct validity in more detail, convergent validity and composite reliability values were calculated. The average variance explained (AVE) was found to be .654, and this value, being above 0.50, indicates that the factor's convergent validity is established (Crano et al., 2023; Zou & Xu, 2023). The composite reliability (CR) coefficient was calculated as .940, indicating that the factor has high internal consistency (Adams & McGuire, 2023; Hiebert et al., 2023). Finally, McDonald's Omega (ω) coefficient was calculated to assess the reliability of the factor and was found to be .867. This value supports the consistent structure of the critical thinking factor (Sorgente et al., 2025). All of these findings are consistent with the 7-item *"I-1. My students question the information they encounter by asking questions such as "Is this true?" or "Could there be another explanation?"; I-2. My students analyze the basis and evidence when evaluating the validity of an idea; I-3. My students critically evaluate their own ideas and the views of others for consistency; I-4. My students actively use critical thinking skills when testing hypotheses in laboratory work; I-5. My students produce alternative solutions by reinterpreting information rather than passively receiving it; I-6. My students can identify contradictions and possible biases by looking at events from different perspectives; I-7. My students remain respectful while engaging in critical inquiry and make this approach a scientific habit."* This demonstrates that the critical thinking factor is a valid and reliable measurement tool.

In the exploratory factor analysis conducted to measure the scientific inquiry factor, 13 items were initially used. However, three items with low factor loadings and related to other factors were removed, and the analysis was completed with 10 items. To examine the construct validity of the scientific inquiry factor, the suitability of the data set for factor analysis was first evaluated. The Kaiser-Meyer-Olkin (KMO) sample adequacy coefficient was calculated as .930, and the Bartlett's sphericity test result was found to be significant ($\chi^2 = 6026.620$; $p < .001$). These findings indicate that the data are suitable for factor analysis (Mindrila, 2017). In the examination conducted with principal component analysis, 10 items with factor loadings ranging from .740 to .855 were grouped under a single factor, and this structure explained 66.177% of the total variance. The high KMO value, significant Bartlett test, and high variance explained ratio indicate that the factor exhibits a strong factorial structure (Finch, 2019; Garson, 2023; Mindrila, 2017). Subsequently, confirmatory factor analysis (CFA) was conducted to validate the obtained factor structure. When examining the model fit indices, the following values were obtained: $\chi^2/df = 3.136$, $p > .001$, CFI = .997, TLI = .984, RMSEA = .076, and SRMR = .015. These results support the model's good fit (Roos & Bauldry, 2021). To examine construct validity in more detail, convergent validity and composite reliability values were calculated. The average variance explained (AVE) was found to be .662, and this value, being above 0.50, indicates that the factor's convergent validity is established (Crano et al., 2023; Zou & Xu, 2023). The composite reliability (CR) coefficient was calculated as .947, indicating that the factor has high internal consistency (Adams & McGuire, 2023; Hiebert et al., 2023). Finally, McDonald's Omega (ω) coefficient was calculated to assess the reliability of the factor and was found to be .943. This value supports the consistent structure of the scientific curiosity factor (Cipresson & Immekus, 2022). All of these findings are based on the 10-item scale: *"I-1. My students generate questions through observation and investigate these questions using the scientific method; I-2. My students can formulate testable hypotheses about*

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

topics that interest them; I-3. My students design and conduct appropriate experiments to test their hypotheses; I-4. My students analyze experiment results and make valid inferences; I-5. My students behave systematically in collecting and recording data during the research process; I-6. My students are not afraid of making mistakes when conducting scientific inquiry and see errors as learning opportunities; I-7. My students produce creative solutions by trying different approaches to solve a problem; I-8. My students understand the importance of each step in the scientific process (observation, hypothesis, experiment, conclusion); I-9. My students are unbiased and objective when evaluating research results; I-10. My students apply their scientific inquiry skills to everyday problems." This demonstrates that the scientific inquiry factor is a valid and reliable measurement tool.

Data Analysis

In the qualitative phase of this study, the theme proposed by Günbayı (2023) was adopted, along with descriptive and content analysis techniques. NVIVO 14 software was used to systematically analyze the data, and the reliability of the analyses was ensured by evaluating the consistency of the coding in accordance with the opinions of three independent field experts. The reliability value of [$K = .911$, $p = .001$] calculated using Fleiss's Kappa coefficient revealed a statistically significant agreement among coders and that the analysis results were highly reliable (Gwet, 2021). Participants' identities were anonymized using the letters A-G to protect their privacy. In the quantitative phase of the study, Model 14, developed by Hayes (2018), was used as a basis, and the analyses were performed using the PROCESS macro 5.0 program. Prior to the analysis, multivariate statistical assumptions were rigorously tested. The VIF values examined to control for multicollinearity ranged from 1.827 to 3.319 (all < 5), and the Durbin-Watson coefficient was found to be 2.109, indicating the absence of linearity issues and autocorrelation, respectively (Blair et al., 2023; Crano et al., 2023). Additionally, the skewness (−0.536 to −0.387) and kurtosis (−0.011 to +0.008) values remaining within the ±2 limits supported that the data met the assumption of multivariate normal distribution (Hiebert et al., 2023; Zou & Xu, 2023). In the study, "Scientific Curiosity" (X) was integrated into the model as an exogenous variable, "Scientific Collaboration" (M) as an instrumental variable, "Critical Thinking" (Y) as an endogenous variable, and "Scientific Inquiry" (W) as a moderating variable. This structure allowed for the simultaneous examination of mediating and moderating effects. Bootstrap analyses were conducted with 5,000 samples at a 95% confidence level, and the significance of indirect effects was evaluated through confidence intervals, providing strong evidence to support the robustness of the model.

Research Results

Qualitative Results

The themes, categories, and codes related to how teachers perceive and define the concepts of scientific curiosity, scientific collaboration, critical thinking, and scientific inquiry are presented in Tables 1, 2, 3, and 4.

Table 1
Themes, Categories, and Codes Related to the Concept of Scientific Curiosity

Theme	Category	Code	Participants
Definition and Function	Initiator of the Scientific Process	Inquiry that begins with curiosity; why–how questions; desire to acquire knowledge	A, B, D, G
	Trigger for Deep Learning	Not remaining on the surface of knowledge; conducting research, making sense of knowledge	A, B, C, D
	Foundation of Scientific Thinking	Focusing on processes such as experimentation, observation, and hypothesis; moving away from memorization	B, E, F
Individual Development and Learning Process	Motivation and Intrinsic Drive	Intrinsic desire to learn; curiosity motivating the individual to take action	C, E
	Self-Directed Learning	Independent research; trying new approaches; independent learning	A, F, G
	Self-Confidence and Problem-Solving Skills	Development of self-confidence through questioning; creative and solution-oriented thinking	F, G

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

Theme	Category	Code	Participants
Educational and Pedagogical Dimension	Laboratory and Applied Learning	The impact of curiosity in experiments; being more active in practical processes	B, E
	Support for Critical Thinking	Moving away from rote learning; generating alternative ideas	D, G
	Teacher Observation and Assessment	The curious student being noticed and encouraged by the teacher	C, F

When Table 1 is examined, it is seen that scientific curiosity plays a multi-layered and effective role in both individual development and scientific thinking. Within the scope of the theme of definition and function, the participants' statements reveal that curiosity is not just a temporary interest, but a fundamental cognitive and emotional dynamic that initiates, sustains, and directs the process of acquiring knowledge. Curiosity is not merely a desire to know, but also an effort to delve into the foundations of knowledge, question its rationale, and make sense of it. In this sense, it transforms the student from a passive recipient into an active learner. As the initiator of the scientific process, curiosity awakens the desire to question cause-and-effect relationships in individuals and, in this sense, triggers the desire to acquire knowledge. According to the participants' views (A, B, D, G), this type of questioning process ensures that students act not only with the intention of acquiring knowledge but also with the intention of producing knowledge. In this context, curiosity is not merely a superficial interest; it is a cognitive tool that encourages in-depth learning. Indeed, the statements of participants A, B, C, and D emphasize that the quality of learning is enhanced by not remaining on the surface of knowledge, but rather by conducting research and engaging in a process of interpretation. Curiosity also increases the orientation towards processes such as experimentation, observation, and hypothesis formation, which form the basis of scientific thinking (B, E, F), distancing the student from a rote approach and directing them towards critical thinking. In this respect, curiosity has a pedagogically transformative function beyond being a mere cognitive stimulus. When evaluated in terms of the theme of individual development and the learning process, it is understood that curiosity is an internal source of motivation and triggers the individual's self-regulatory behaviors toward learning. As emphasized by participants C and E, the inner desire to learn motivates the student, while participants A, F, and G state that this process strengthens self-directed learning behaviors and develops the student's ability to conduct independent research. In this context, self-confidence and problem-solving skills developed through asking questions and trying new approaches (F, G) contribute to the student's development as a more creative and solution-oriented individual in both their academic and personal lives. In terms of educational and pedagogical themes, the impact of curiosity on the learning environment is noteworthy. In particular, it has been observed that curiosity makes students more active and makes learning experiential (B, E), especially in laboratory and applied processes. In addition, as noted by participants D and G, curiosity supports critical thinking and enables the development of alternative ways of thinking. Finally, in the teacher observation and evaluation dimension, the views shared by participants C and F indicate that when a curious student is noticed and encouraged by the teacher, it positively impacts the learning process. The participants' views are provided below.

> [...] Scientific curiosity begins when students question a situation they encounter. Asking questions such as why, how, and when is the first sign of this curiosity. Curious students do not just listen to the lesson; they research and try to access different sources. This makes learning permanent and meaningful [A].

> [...] For me, scientific curiosity is a desire to delve into the background of knowledge. Students are curious not only about the result but also about the process. For example, instead of memorizing the result of an experiment, asking "Why did this result come out this way?" is a sign of scientific curiosity. This type of curiosity forms the basis of scientific thinking [B].

> [...] Scientific curiosity is an innate urge to understand nature. It is related to the desire to learn the mechanisms behind seemingly ordinary events. Curious students ask more questions and are not easily satisfied, which deepens the learning process. Seeing this in students really motivates me [C].

> [...] When a student asks questions such as "Why is it like this?" or "What would happen if it were different?" on a subject, it is a clear sign of scientific curiosity. Such questions move them away from rote learning and help them develop their own thought systems. Scientific curiosity is not just about knowing, but about trying to understand. This also brings critical thinking [D].

> [...] I believe that scientific curiosity is the driving force behind learning. Curious students read more, try more, make mistakes, but do not give up. In this process, they both develop themselves and discover the nature of science. The difference between curious students and others is particularly evident in laboratory applications [E].

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

> [...] Scientific curiosity is when a student is not satisfied with a subject and wants more. A student who asks, "Is there another way to do this?" has taken the first step toward scientific thinking. Science cannot develop without curiosity, because every discovery begins with a question. That is why I value students who ask questions and question things in class [F].

> [...] When a student asks, "Why are we doing it this way?" or "What if we tried something else?", it is the most beautiful example of scientific curiosity. Such questions make learning active. Scientific curiosity is not just about acquiring knowledge, but about searching for new ways with that knowledge. This approach also develops the student's self-confidence and problem-solving skills [G].

When participants' statements are examined, it is seen that there is a common understanding of the role of scientific curiosity in the student's learning process, but this understanding is expressed in various dimensions. All participants define scientific curiosity as a driving force that goes beyond superficial knowledge acquisition and encourages deep thinking. For example, participants A and B emphasize that curiosity transforms the student into an active learner who does not settle for mere information but questions the process and cause-and-effect relationships. Participant C, on the other hand, defines this approach as an internal desire to explore nature and events, noting that curiosity deepens the learning process. Participants D and F view curiosity as an element that moves away from rote learning and supports questioning, thinking, and the search for meaning, particularly highlighting its role in the development of the student's own thought system. Participant E describes curiosity as the "driving force" of learning, emphasizing the student's development through trial and error, while participant G underscores that scientific curiosity involves not only acquiring knowledge but also creatively seeking new paths with that knowledge and solving problems. When these statements are evaluated together, it becomes clear that scientific curiosity is a multidimensional structure that meaningfully nourishes the student's intellectual development, critical thinking skills, motivation to learn, and participation in scientific processes.

Table 2
Themes, Categories, and Codes Related to the Concept of Scientific Collaboration

Theme	Category	Code	Participants
Definition and Function	Shared Goals and Ideas	Working together toward a common goal; sharing knowledge, contributing to each other	A, D, F
	Diversity and Richness of Perspectives	Different perspectives; achieving stronger results together	B, C, G
	Interdisciplinary Interaction	Drawing from different fields; thinking in a multifaceted way, intellectual diversity	C, G
Individual and Social Development	Empathy, Respect, and Humility	Empathy; valuing others' ideas, recognizing one's identity in collaboration	B, E
	Social and Scientific Responsibility	Taking responsibility; awareness of collective production, focusing on collective success	D, F
	Personal Contribution and Learning	Expressing one's own ideas; learning from others, collaboration as an opportunity for development	A, E
Educational and Scientific Process	Scientific Application Practice	The working style of real scientists; discussion, compromise, and collaborative production	D, F, G
	Teamwork and Skill Development	Interaction within the team; direct development of scientific skills, lifelong gains	G, B

When Table 2 is examined, it is understood that collaboration-based learning offers a strong structure in student development in both individual and collective terms. In terms of definition and function, collaboration is not just an activity carried out together; it is defined as the sharing of ideas, the exchange of information, and the deepening of learning through mutual contribution toward a common goal (A, D, F). In particular, the emphasis on diversity and richness of perspective (B, C, G) enables students to broaden their horizons by encountering different points of view and to achieve stronger results together. Interdisciplinary interaction (C, G) enables students to experience intellectual diversity by drawing on different fields, turning them into well-rounded individuals. In the context of individual and social development, values such as building empathy among students, respecting others' ideas, and sharing ideas with humility (B, E) are seen to provide important gains in terms of social learning.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

In this process, students develop not only academic skills but also social responsibility and a sense of collective production (D, F). According to the participants' statements, collaborative work supports students in recognizing their own contributions, freely expressing their ideas, and demonstrating personal development by learning from others (A, E). When evaluated in terms of educational and scientific processes, it is understood that students experience scientific practices not only theoretically but also practically and collaboratively (D, F, G). Discussion, compromise, and collaborative production enable students to learn in an environment similar to that of real scientific communities. In addition, teamwork (G, B) contributes not only to the development of academic skills but also to the development of communication, coordination, and lifelong collaboration skills. In short, collaboration among students emerges as an element that enriches learning not only in terms of knowledge transfer but also in many areas such as critical thinking, taking social responsibility, and active participation in scientific production. The participants' views are presented below.

> [...] Scientific collaboration is working together to exchange ideas toward a common goal. Students share their knowledge within the group and take into account the contributions of others, which creates this process. This type of interaction enriches learning and develops social skills. Science does not progress alone, but rather through collective thinking [A].

> [...] For me, scientific collaboration is about bringing together different perspectives to achieve stronger results. When students discuss a problem, they learn from each other and develop their own ideas. This process teaches not only knowledge but also empathy and patience. A scientific process without collaboration is incomplete [B].

> [...] Scientific collaboration is the process of combining the knowledge, experience, and skills of multiple individuals. This is not merely a division of labor; it is also a process of thinking and creating together. Students learn to draw from different fields, thereby developing an interdisciplinary perspective [C].

> [...] The foundation of scientific collaboration is students discussing, defending their ideas, and ultimately reaching a common solution while working together. This is very valuable in terms of both academic and personal development. In addition, the satisfaction of producing something together encourages them to do more research. Scientists do the same [D].

> [...] In my opinion, scientific collaboration means not being limited to individual knowledge, but being open to thinking together. Collaboration allows students to recognize their own contributions and shows them that there is much to learn from others. This brings humility and sharing. It teaches students that science is a collective process [E].

> [...] Scientific collaboration is formed when multiple students work toward a common goal and take responsibility. In this process, students both express their own ideas and learn to listen to others. Scientific collaboration emphasizes collective success over individual success. This is how things work in the real world of science [F].

> [...] Scientific collaboration is a productive process that brings together different talents. It is not just about working together; it is about understanding, agreeing, and coming to a common understanding. The interaction that students demonstrate while working in teams directly develops their scientific skills. These skills accompany them throughout their lives [G].

When the participants' statements are examined, it is evident that there is a strong and multidimensional common understanding of scientific collaboration. All participants do not view scientific collaboration as merely working together; rather, they define it as a productive and transformative process based on the exchange of ideas. Participant A approaches collaboration in terms of knowledge sharing and the development of social skills, emphasizing that science is inherently a collective process. Participant B evaluates this process as a means of blending different perspectives to achieve higher-quality outcomes, while also emphasizing that emotional skills such as empathy and patience are developed through collaboration. Participant C interprets scientific collaboration through interdisciplinary interaction and defines this process as "thinking and producing together," pointing to a deep cognitive contribution. Participant D focuses on the processes of joint discussion, defending ideas, and producing common solutions among students, emphasizing that this interaction is important for both academic and personal development. Participant E addresses collaboration in the context of the collective nature of knowledge, noting that the process encourages humility and a culture of sharing among students. Participant F states that scientific collaboration requires taking responsibility in line with common goals, emphasizing collective success over individual success. Participant G defines collaboration not only as a technical division of labor but also as a process based on understanding, compromise, and collective reasoning, noting that this process contributes to students' scientific skills and long-term development. When all these views are considered together, scientific collaboration emerges not merely as an academic task but as a holistic form of interaction that transforms students cognitively, emotionally, and socially, bringing them closer to the true nature of science.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 3
Themes, Categories, and Codes Related to the Concept of Critical Thinking

Theme	Category	Code	Participants
Definition and Function	Questioning and Evaluating Information	Not accepting information at face value; questioning, evaluating sources	A, B, D, F
	Analytical and Independent Thinking	Critical reasoning; developing independent thinking	B, D, E
	Reconstructing Information	Questioning the source and validity of information; producing information	E, F
Application and Skills	Hypothesis Testing and Scientific Applications	Testing hypotheses; laboratory applications; verifying information	C, F
	Alternative Solutions and Multifaceted Perspectives	Being able to see things from different perspectives; recognizing contradictions, alternative solutions	G, C
Individual Development and Impact	Mental Independence and Critical Awareness	Questioning one's own thoughts; mental independence, being a free individual	D, G
	The Importance of Critical Thinking in Education	The importance of fostering critical thinking; its critical role in the learning process	E, F

When Table 3 is examined, it is seen that critical thinking skills play a fundamental role in the student's learning process in terms of both cognitive and personal development. Within the scope of the definition and function theme, it is important for students not to accept information as it is, but to question it, evaluate its basis, and approach it with a critical distance (A, B, D, F). In this process, the student becomes not only a consumer but also a subject who reconstructs and produces knowledge (E, F). Analytical and independent thinking skills (B, D, E) enable the student to form their own thought system and reach independent judgments through critical reasoning. In the theme of application and skills, it is noteworthy how critical thinking is combined with concrete scientific processes. In particular, hypothesis testing and laboratory applications (C, F) enable students to develop their ability to verify information and participate directly in scientific processes, making their ideas testable. The ability to generate alternative solutions and develop a multifaceted perspective (G, C) enables students to see different points of view, recognize contradictions, and develop more flexible and creative solutions. In this respect, critical thinking is reflected in students not only as a theoretical but also as an applied skill. In the context of individual development and impact, it is noteworthy that students gain mental independence (D, G) and develop intellectual awareness by questioning their own thoughts. This contributes to students constructing their own thought structures as free and responsible individuals. Similarly, the place of critical thinking in the educational process (E, F) reveals that this skill is an indispensable tool not only in terms of individual development but also in terms of improving the quality of learning. The participants' statements reflect a common approach that the acquisition of critical thinking should be one of the fundamental goals of education. In short, critical thinking transforms students into active subjects who not only access knowledge but also structure it; who not only learn but also question and guide their learning. In this sense, critical thinking is considered a central skill that nourishes student development in both scientific and educational contexts. The participants' views are presented below.

> *[...] Critical thinking is the ability to question information rather than accepting it at face value. The student's thinking, "Is this correct? Could there be another explanation?" is the beginning of this process. This way of thinking enables true learning by avoiding rote memorization. Progress in science also begins with this questioning [A].*

> *[...] For me, critical thinking is the process of evaluating the basis of an idea before blindly accepting it. Students do not just look for the right answer, they also try to understand why the information given is correct. This develops both analytical and independent thinking. This is the cornerstone of scientific reasoning [B].*

> *[...] A critically thinking student questions both their own ideas and those of others. This questioning is not disrespectful; it is a way of verifying information. Testing hypotheses, especially in laboratory work, is an application of this skill. This competence distances the student from superficial thinking [C].*

> *[...] Critical thinking is the student's analysis of the information they encounter rather than immediately believing it, evaluating its consistency. They question not only what the teacher says but also what goes through their own mind. This increases the individual's mental independence. Critical thinking is a fundamental characteristic of free and scientific individuals [D].*

> *[...] In my opinion, critical thinking is the courage to not settle for information but to reconstruct it. Students question both the source and validity of information. This transforms them from mere consumers of information into producers of information. It is very important to impart this skill in education [E].*

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

[...] Critical thinking is not accepting everything one hears as true but seeking evidence. The student's skeptical approach to information leads to new questions and deeper research. This approach also plays a fundamental role in the development of science. It is very valuable to see this awareness in students [F].

[...] Critical thinking involves being able to look at events from different angles and recognize contradictions. A student who can think of not just one solution, but alternative solutions has acquired this skill. This advances them both academically and in terms of life skills. A critical perspective is the spirit of scientific progress [G].

When the participants' statements are examined, it is understood that critical thinking is seen as an indispensable skill in the student's intellectual development and scientific learning process. The main point on which the participants agree is that critical thinking is not only a process of questioning knowledge but also brings with it mental independence, in-depth learning, and scientific productivity. Participant A defines this skill as the student's questioning of knowledge rather than accepting it directly, noting that it moves away from a rote approach and forms the basis of scientific progress. Participant B defines critical thinking as the process of analyzing and understanding the reasons behind an idea, emphasizing that it develops analytical thinking and independent decision-making skills. Participant C emphasizes that this skill involves questioning not only the ideas of others but also one's own ideas, and states that this process is concretized in the laboratory environment through hypothesis testing. Participant D relates critical thinking to the individual's mental freedom, arguing that the process of evaluating both external and internal sources of information brings the student closer to the identity of a free individual. Participant E views critical thinking not only as approaching knowledge with skepticism, but also as the courage to reconstruct knowledge, noting that this process transforms students from knowledge consumers to knowledge producers. Participant F similarly states that a skeptical approach deepens the search for knowledge and that this awareness is essential for scientific development. Participant G associates critical thinking with the ability to develop a multifaceted perspective and recognize contradictions, emphasizing that this ability contributes not only to the student's academic capacity but also to their ability to solve problems in life. When these statements are evaluated as a whole, critical thinking emerges as a multidimensional mental competence that enables students to go beyond passively receiving information and engage in an active, questioning, and productive learning process.

Table 4
Themes, Categories, and Codes Related to the Concept of Scientific Inquiry

Theme	Category	Code	Participants
Definition and Function	Fundamentals of the Scientific Process	Observing, asking questions, forming hypotheses, and testing them	A, C, D, F, G
	Active and Effective Learning	Not being a passive recipient; taking on the role of researcher, active learning	A, C, D
	Trial and Error and Patience	Not being afraid of making mistakes; systematic testing, patience, and attention to detail	B, E, G
Personal Development and Responsibility	Conscious and Methodical Work	Systematically questioning information; conscious and methodical work	E, F
	Independence and Responsibility	Taking responsibility for learning; independent thinking and decision-making	F, G
Scientific Approach and Skills	Evidence-Based Assessment	Decision-making based on evidence; forming hypotheses, conducting experiments, and evaluating results	G, A, F
	Multifaceted and Systematic Thinking	Systematic and multifaceted thinking; thinking like a scientist	G, E

When Table 4 is examined, it is seen that scientific thinking skills are reflected in the student's learning process in an effective and transformative way. Within the scope of the definition and function theme, it is understood that the student experiences the scientific process not only as a theoretical set of knowledge but also as active research processes such as observing, asking questions, forming hypotheses, and testing (A, C, D, F, G). In this way, the student moves away from the role of a passive recipient of knowledge and takes on the identity of a researcher, becoming a subject who participates in, questions, and produces the process (A, C, D). In addition, the trial-and-error approach and patience-requiring stages involved in the scientific process (B, E, G) support the student in overcoming their fear of making mistakes, progressing systematically, and developing careful observation skills.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Within the framework of individual development and responsibility, it is observed that students go beyond superficial acquisition of knowledge and develop the habit of conscious and methodical questioning (E, F). This habit not only enables students to access knowledge but also to take responsibility for their own learning process. As emphasized by participants F and G in particular, this process enables students to think independently, develop their decision-making skills, and adopt a more autonomous attitude toward learning. Within the theme of scientific approach and skills, it is observed that students focus on evidence-based thinking in the scientific process (G, A, F). Through processes such as hypothesis formation, experimentation, and evaluation of results, students do not merely learn information; they test, evaluate, and ground it in solid foundations. As emphasized in the statements of participants G and E, this process develops systematic and multifaceted thinking skills in students, enabling them to think like scientists. In short, these findings show that students internalize scientific thinking not only as a content area but also as a mental attitude and learning strategy. In this respect, science process-based learning transforms into a multidimensional learning experience that empowers students both cognitively and personally. The participants' statements are provided below.

> *[...] Scientific inquiry is the process of asking questions based on observations, forming hypotheses, and testing these hypotheses. Students should be curious not only about the result but also about the path leading to that result. In this process, they conduct experiments, collect data, and make inferences. In other words, scientific inquiry is active learning itself [A].*

> *[...] For me, scientific inquiry is the process of investigating why and how knowledge is formed. Students identify a problem, think about possible solutions, and test them. They are not afraid of making mistakes because the nature of inquiry is trial and error. This is the fundamental way science progresses [B].*

> *[...] Scientific inquiry is a process in which the student is not a passive recipient but an active researcher. The first step in this process is to try to establish a cause-and-effect relationship in response to an event. Then they observe, develop hypotheses, and design experiments. In this way, they learn all the steps of the process of acquiring knowledge [C].*

> *[...] The scientific inquiry process begins with the student asking, "Why did this happen?" Then comes the question, "How can I test this?" These two questions already introduce them to the scientific way of thinking. I see that when students acquire this approach, they achieve deeper and more lasting learning [D].*

> *[...] I believe that scientific inquiry is a process that progresses alongside critical thinking. It means not only questioning a piece of information but also trying to test it systematically. Students who understand this process work more consciously and methodically. They also become more patient and attentive [E].*

> *[...] Scientific inquiry is the process of producing explanations for an event observed by the student and testing these explanations. This process encompasses the basic steps of the scientific method. When students acquire this skill, they begin to take responsibility for their own learning. Independence in science stems from this [F].*

> *[...] Scientific inquiry requires deciding what is true not from outside sources but through evidence. The student formulates a hypothesis, conducts an experiment, and evaluates the results. This process forces them to think systematically, be patient, and look at things from multiple perspectives. This is the most concrete example of thinking like a scientist [G].*

When participants' statements are examined, it is understood that scientific inquiry is seen as a fundamental learning process that transforms students from passive recipients of information into active and systematic producers of knowledge. All participants agree that scientific inquiry not only provides access to knowledge but also contributes directly to the development of cognitive skills, the assumption of responsibility for learning, and the process of thinking scientifically. Participant A defines this process as the essence of active learning, consisting of the steps of observation, hypothesis formation, and testing; participant B views scientific inquiry as a trial-and-error process and emphasizes that students should seek solutions without fear of making mistakes. Participant C states that scientific inquiry transforms students into researchers and that learning deepens as students experience all the steps of acquiring knowledge. Participant D focuses on the fundamental questions that trigger this process – "Why did this happen?" and "How can I test this?" – and states that this inquiring approach leads to lasting learning. Participant E emphasizes that scientific inquiry is an integrated process with critical thinking, stating that students who are familiar with this method work more systematically, carefully, and patiently. Participant F evaluates this process within the framework of the basic steps of the scientific method and states that scientific inquiry develops learning responsibility and independence in students. Participant G similarly states that scientific inquiry is not only about acquiring knowledge but also about reaching the truth through evidence, and that this process encourages students to think in a multifaceted, patient, and systematic way. When these statements are evaluated together, scientific inquiry emerges as the most concrete and functional form of scientific thinking, supporting both the cognitive and emotional development of students and nurturing qualities such as systematic thinking, evidence-based reasoning, and responsibility for learning.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

Quantitative Results

The results of the correlation analysis regarding scientific curiosity, scientific collaboration, critical thinking, and scientific inquiry are presented in Table 5, while the results of the analysis regarding the moderated mediation role of scientific inquiry in the association between scientific curiosity and critical thinking through scientific collaboration are presented in Table 6.

Table 5
Distribution Levels of Measurement Tools

Scales	*X*	*M-*	*Y*	*W*	*M*	SD
Scientific Curiosity (X)	1				3.60	0.79
Scientific Collaboration (M-)	.815**	1			3.69	0.75
Critical Thinking (Y)	.858**	.884**	1		3.58	0.81
Scientific Inquiry (W)	.624**	.654**	.690**	1	3.53	0.90

*$p < .05$; **$p < .01$; ***$p < .001$, N = 371 teachers participated in the survey.

When Table 5 is examined, it can be seen that there are strong and significant positive correlations between students' scientific curiosity, scientific collaboration, critical thinking, and scientific inquiry scores. As scientific curiosity increases, students' tendencies toward scientific collaboration ($r = .815$, $p < .001$) and critical thinking ($r = .858$, $p < .001$) also rise; similarly, the association between scientific curiosity and scientific inquiry is also significant ($r = .624$, $p < .001$). The association between students' scientific collaboration and critical thinking scores is quite high ($r = .884$, $p < .001$), suggesting that collaborative work experiences may support depth of thinking. Additionally, the significant correlations between scientific collaboration and scientific inquiry ($r = .654$, $p < .01$) and between critical thinking and scientific inquiry ($r = .690$, $p < .001$) imply that students actively participate in the processes of discussing, questioning, and restructuring knowledge. When looking at the average values, the highest score belongs to the scientific collaboration variable ($M = 3.69$, $SD = 0.75$), followed by scientific curiosity ($M = 3.60$, $SD = 0.79$), critical thinking ($M = 3.58$, $SD = 0.81$), and scientific inquiry ($M = 3.53$, $SD = 0.90$); all standard deviations being below 1 indicate that the scores are relatively homogeneously distributed.

Table 6
Moderated Mediation Effect of Scientific Inquiry

Variables	Scientific Collaboration (M)			Critical Thinking (Y)		
	β	LLCI	ULCI	β	LLCI	ULCI
Scientific Curiosity (X)	.803***	.745	.862	.388***	.314	.463
Scientific Collaboration (M)	-	-	-	.513***	.434	.592
Scientific Inquiry (W)	-	-	-	.123***	.075	.172
M*W (Interaction)	-	-	-	.046***	.008	.084
R^2		.664			.851	
Indirect Effect*				-	-	-
Low Scientific Inquiry	.379***	.256	.518	-	-	-
Medium Scientific Inquiry	.412***	.293	.550	-	-	-
High Scientific Inquiry	.445***	.324	.584	-	-	-
Moderated Mediation Index	.037***	.010	.064			

Notes: *$p < .05$; **$p < .01$; ***$p < .001$ N = 371 teachers participated in the survey. [Scientific Curiosity→ Scientific Collaboration → Critical Thinking]*, LLCI = Sub-Confidence Interval; ULCI= Upper Confidence Interval.

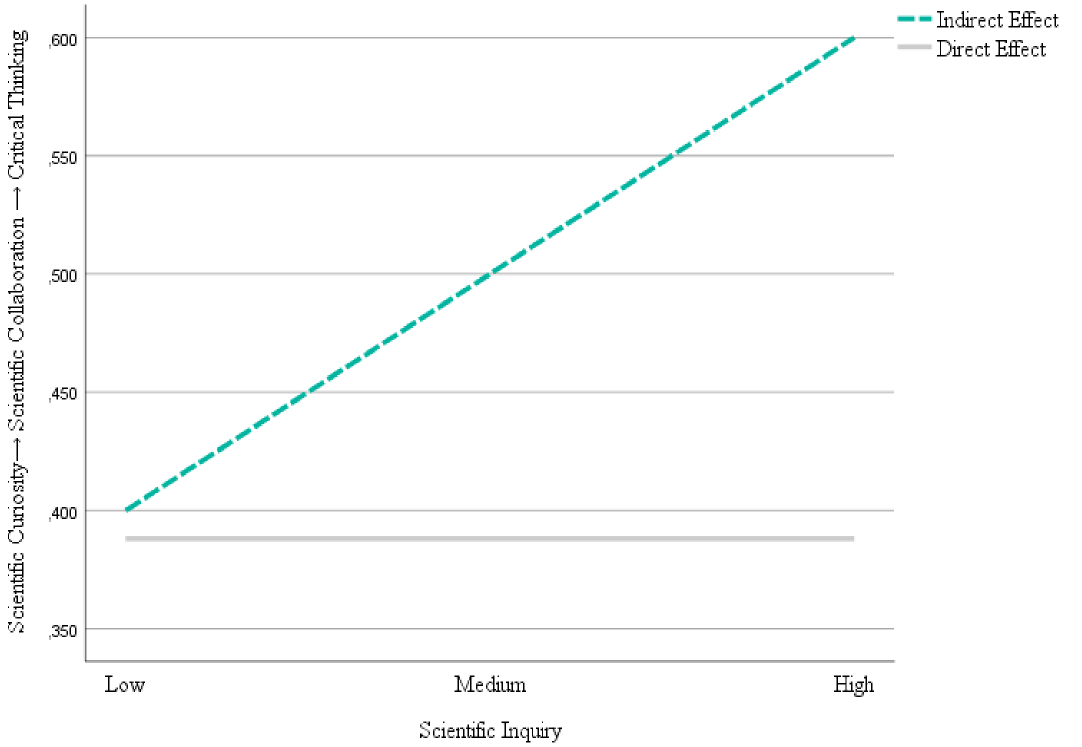
https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

When Table 6 is examined, it is seen that students' levels of scientific curiosity significantly predict both scientific collaboration (β = .803, $p < .001$) and critical thinking skills (β = .388, $p < .001$). Furthermore, scientific collaboration is also a significant predictor of critical thinking (β = .513, $p < .001$). These findings indicate that students' scientific curiosity is not merely an individual trait but also shapes both their tendency to collaborate and their capacity for critical thinking. The scientific inquiry variable in the model also has a significant and positive direct effect on critical thinking (β = .123, $p < .001$). Furthermore, the interaction term between scientific collaboration and scientific inquiry is also significant (β = .046, $p < .001$); this indicates that the effect of scientific collaboration on critical thinking varies depending on the student's level of scientific inquiry. When examining the explanatory power of the model, high R^2 values of .664 for explaining scientific collaboration and .851 for explaining critical thinking were obtained, indicating that the model is quite robust. When examining conditional indirect effects, the indirect effect from scientific curiosity to critical thinking was β = .379, $p < .001$ for students with low scientific inquiry levels; β = .412, $p < .001$ for students with moderate levels; and β = .445, $p < .001$ for students with high levels. These results reveal that as the level of scientific inquiry increases, the indirect effect of scientific curiosity on critical thinking also strengthens. Finally, the "moderated mediation index" β = .037, CI [.010, .064] was found to be statistically significant. This finding shows that the effect of students' scientific curiosity levels on critical thinking occurs indirectly through scientific collaboration and that this indirect effect varies depending on the level of scientific inquiry. In this context, it can be said that students with high scientific inquiry skills are more effective at transforming their scientific curiosity into critical thinking.

When examined in Figure 1, the line representing indirect effects shows a significant increase as the level of scientific inquiry progresses from low to high. This situation reveals that, rather than a direct link between students' scientific curiosity and critical thinking skills, it is a mechanism operating through scientific collaboration that is effective. In other words, scientific collaboration both nurtures students' curiosity and supports their critical thinking, leading to a noticeable increase in their scientific inquiry levels. The difference between students with low levels of scientific inquiry and those with high levels of inquiry is particularly evident in the indirect effect. In contrast, the line representing the direct effect is almost horizontal, indicating that there is no significant change in the level of scientific inquiry at low, medium, and high levels.

Figure 2
Moderated Mediation Effect of Scientific Inquiry



https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

This implies that scientific curiosity and critical thinking alone are not sufficient to sufficiently stimulate the student's inquiring attitude, and that intermediaries such as social interaction (scientific collaboration) are needed to strengthen the association between them. In short, the graph reveals that scientific collaboration plays a critical role in developing students' scientific inquiry capacities and that the impact of this mediator is much stronger than direct effects. This finding emphasizes the importance of designing and encouraging collaborative scientific activities in learning environments.

Discussion

The qualitative findings of the study reveal that teachers' perceptions of scientific curiosity, scientific collaboration, critical thinking, and scientific inquiry are consistent with student-centered learning approaches and have a multidimensional and pedagogically transformative structure. Teachers' statements reflect an approach that transforms students from passive recipients of information into active agents, encouraging skills such as self-regulation, independence, critical reasoning, and scientific productivity. These findings are highly consistent with the existing literature and theoretical approaches (Antink-Meyer et al., 2023; Chaparro-Banegas et al., 2024; Dehghanzadeh et al., 2024; Forman, 2020; Keengwe, 2022; Recker, 2021; Ribosa & Duran, 2022; Suwono et al., 2021; Willis & Willis, 2020). First, the concept of scientific curiosity was defined by teachers not only as a trigger for the learning process but also as the fundamental motivational source for deep learning, meaning construction, and scientific thinking. This definition aligns with the "motivation to discover" emphasized in Bruner's (1961) constructivist theory (Sweller, 2009). The student's questioning and attempt to make sense of the process through curiosity, rather than passively receiving information, recalls both Piaget's concept of cognitive disequilibrium and Dewey's emphasis on experience- and problem-based learning. Indeed, the findings in the study that curiosity directs students away from rote learning toward knowledge production and develops independent learning skills are consistent with Guthrie and Wigfield's (2000) theory of intrinsic motivation. However, an important critical point here is whether curiosity can be systematically supported in the pedagogical environment. The literature emphasizes that teaching strategies must be consciously structured for curiosity to be a sustainable learning engine (Judijanto et al., 2025; Karwal et al., 2023; Madison, 2023; Nicolopoulou et al., 2021; Whitworth, 2025). Although the teachers participating in the study were aware of this potential, there is limited data on what strategies they actually implemented. This suggests that, although teachers' perceptions are positive in terms of supporting students' curiosity, there may still be a gap in terms of translating this into pedagogical practice. On the other hand, findings on scientific collaboration show that interaction among students nourishes not only academic but also social-emotional development. In particular, exposure to different perspectives, empathy development, and collective production emphasize Vygotsky's (1978) social constructivism theory. This approach, which argues that learning is constructed within a social context, views collaboration not merely as a tool but as learning itself. The ways in which participating teachers interpret scientific collaboration are parallel to Johnson & Johnson's (1985) theory of collaborative learning. According to this theory, when students work toward common goals, both their academic achievement and social skills improve. However, the fact that teachers mostly define scientific collaboration in terms of values and attitudes gives the impression that they emphasize the cognitive dimension of collaboration relatively less. However, research and related literature (Abegglen et al., 2023; Chen et al., 2023; Forbes, 2022; Muchie et al., 2024; Pu & Barnard, 2025; Su et al., 2017) indicate that effective collaboration environments must also encompass cognitive processes such as planned task distribution, interaction, and individual responsibility. In this context, while it is positive that teachers' views focus on affective gains, there is a need to develop awareness of strategies that will reinforce the academic outcomes of collaboration. However, the concept of critical thinking has been defined by teachers in the context of students questioning knowledge, producing alternative solutions, and gaining mental independence. This approach aligns with Ennis' (1985) components of critical thinking, which include analysis, evaluation, inference, and decision-making skills. The participants' view of this skill as the basis of scientific progress also aligns with Paul and Elder's (2006) theoretical framework, which positions critical thinking as a way of life. However, the fact that teachers' statements largely focus on individual awareness and mental freedom indicates that the structural and cultural dimensions of critical thinking are not sufficiently addressed. In this context, teachers' tendency to view critical thinking more as an individual competence means that critical pedagogy overlaps with the understanding of critical thinking only to a limited extent (Book, 2024; Cottrell, 2023; Hanscomb, 2023; Kirk et al., 2023; McPhee & Cox, 2024; Paul & Elder, 2020). Finally, the concept of scientific inquiry has been defined in teachers' statements as a systematic form of learning that encompasses the processes of observation, hypothesis formation, testing, and drawing conclusions. This approach aligns with the fundamental principles of the scientific method (Anupam,

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

2022; Bagdi et al., 2024; Bansal & Ramnarain, 2023; Cook & Wheeler, 2023; Ninos, 2023; Shearmur, 2020; Singh et al., 2023), it emphasizes the importance of constructivist learning environments that encourage students to take on the role of researchers in the learning process. Furthermore, these findings align with the four levels of learning in Schwab's (1962) "scientific inquiry" model. However, teachers' views that students acquire higher-order skills such as systematic thinking and tolerance for error in the scientific inquiry process contradict traditional approaches to error in education. It is debatable whether the right-wrong-centered assessment systems that are still dominant in the Turkish education system support such process-oriented approaches. Therefore, it can be said that teachers' intentions to support such skills may remain limited unless they are supported by systemic practices.

The quantitative findings of the study show that there are strong and meaningful connections between students' scientific curiosity, scientific collaboration, critical thinking, and scientific inquiry skills. This reveals that learning processes are shaped not only by individual cognitive factors but also by social interaction and inquiry-based experiences. First, the strong associations between scientific curiosity and both scientific collaboration and critical thinking suggest that students' natural inclinations toward learning may have a transformative effect on their social and intellectual development. This finding is consistent with the relevant literature and previous research, which have shown similar patterns (Bjerknes et al., 2023; Dos Santos & Krause, 2017; Elder & Paul, 2020; Fasko & Fair, 2020; Liu, 2020; Meyer et al., 2024; Pu & Xu, 2023; Rousseau & van Gelder, 2024; Shahriary et al., 2020). Curiosity functions as an internal spark that initiates learning; however, this spark only transforms into sustainable learning when appropriate social and cognitive environments are provided. In this sense, social-cognitive interactions such as collaboration and questioning play a decisive role in the transformation of individual curiosity into critical thinking. The research results reveal that scientific collaboration serves as an important bridge in the process of developing students' critical thinking skills. It is observed that meaningful interactions between students not only enable the sharing of knowledge but also reconstruct thought structures. This finding aligns with Vygotsky's (1978) social constructivist approach, supporting the idea that learning develops through interaction in a social context. In particular, scientific group work contributes to students developing different perspectives, learning evidence-based thinking, and enhancing their ability to evaluate alternative viewpoints. This is similar to the relevant literature and research, which have emphasized the benefits of collaboration (Fan et al., 2023; Hou et al., 2020; Lee & Haupt, 2020; Nahar & Tayem, 2024). The role of scientific inquiry in the study is noteworthy in terms of students experiencing scientific thinking not only as a passive process of acquiring knowledge but also as an active process of research and problem solving. Inquiry-based learning environments encourage students to generate questions about topics they are curious about, develop hypotheses about these questions, and use strategies to test these hypotheses. In this context, the inquiry process becomes not only a learning method but also a mental habit that supports the student's cognitive development. A particularly noteworthy finding is that as students' level of scientific inquiry increases, the association between scientific curiosity and critical thinking becomes more pronounced. This situation shows that individual curiosity can only evolve into deep thinking and meaningful learning when the student has an inquiring attitude. In other words, as students develop scientific inquiry skills, they are able to express their curiosity in a more systematic and critical manner, which advances their scientific thinking skills to a higher level. In this context, the research results are consistent with the existing literature, which has highlighted similar relationships (Chatfield, 2022; Concannon et al., 2020; Dave, 2024; Gai et al., 2022; Kenett et al., 2023; Mahat & Kandel, 2023; Paavola & Shook, 2021; Pollarolo et al., 2022; Shellito, 2020; Wulff, 2022). However, Chin & Osborne (2008) have noted that students' active participation in scientific inquiry processes increases their depth of thinking, while Kuhn (1999) emphasizes the importance of peer interaction and discussion environments in the development of critical thinking. Similarly, Mercer & Littleton (2007) have demonstrated how collaborative learning transforms individual thinking skills. When evaluated together with these studies, the findings show that students' individual learning tendencies can only be transformed into higher-level skills when integrated with social and cognitive support. From a critical perspective, this research clearly demonstrates that students' learning processes are multidimensional. It is not enough for students to simply be curious; they need social environments where they can structure their curiosity, research-based activities, and a learning climate that is open to questioning. Otherwise, individual learning motivation remains limited, and lasting and deep learning does not occur. Therefore, learning environments should adopt an approach that focuses not only on individual success but also on collective productivity and the construction of shared knowledge.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Conclusions and Implications

This study comprehensively examined the correlations between students' scientific curiosity, scientific collaboration, critical thinking, and scientific inquiry skills in a multidimensional manner using both quantitative and qualitative data, thereby revealing the individual and social components of contemporary learning approaches. The findings show that learning cannot be reduced to individual cognitive processes alone; it is a complex structure shaped by factors such as social interaction, affective participation, and the pedagogical environment. The transformation of students' scientific curiosity into sustainable learning is only possible with the existence of social, cognitive, and inquiry-based learning environments where this curiosity can be structured. Scientific collaboration not only enables the sharing of knowledge but also the collective restructuring of thought, which supports the development of critical thinking skills. In particular, inquiry-based learning processes have been observed to nurture students' scientific thinking habits and strengthen the association between scientific curiosity and critical thinking. Qualitative data reveal that teachers' pedagogical perceptions of these concepts align with a student-centered, discovery-based, and constructivist understanding; however, they also indicate that the impact of these positive trends may be limited if they are not translated into strategic planning at the implementation level. This situation highlights the need for teacher education programs to focus not only on theoretical knowledge but also on concrete pedagogical strategies for integrating this knowledge into classroom practices. Theoretically, the research findings are highly consistent with contemporary learning theories such as constructivist learning theory, social constructionism, and intrinsic motivation theory, providing a comprehensive theoretical framework that explains how individual curiosity interacts with social collaboration and inquiry processes in the development of scientific thinking. In this context, the emphasis on the need to support individual learning motivations with social learning contexts makes important contributions to the educational research literature. From an applied/practical perspective, this research highlights the critical role of learning environments that trigger students' curiosity and encourage collaboration in developing higher-order cognitive skills such as critical thinking and scientific inquiry in classroom applications. Educational programs should be enriched with interdisciplinary and inquiry-based activities that address these components in a holistic manner. It is recommended that in-service training programs be restructured and pedagogical leadership be strengthened so that teachers' awareness of these skills can be reflected in classroom practices. In addition, assessment processes should focus not only on outcomes but also on the process, allowing for freedom to make mistakes and encouraging a learning climate.

Recommendations

Research findings highlight the importance of educational policies and pedagogical approaches that support the development of students' scientific curiosity, collaboration, critical thinking, and scientific inquiry skills. In this context, teacher training programs must go beyond theoretical knowledge and include practical strategies that enable these skills to be effectively transferred to the classroom. It is important for teachers to gain practical skills in in-service training, for learning environments to be designed in a way that encourages curiosity and supports discovery, and for interdisciplinary, student-centered projects to be implemented. Assessment systems should focus on the process and provide meaningful feedback to students.

Limitations

This study has several limitations. First, the qualitative data are drawn from a small number of teachers, which may limit the generalizability of the findings, and their perspectives may not represent teachers in different sociocultural contexts. Additionally, the RMSEA value of the Scientific Curiosity Factor was .076, indicating a slightly suboptimal model fit. The quantitative data were cross-sectional, preventing the examination of longitudinal changes in interactions among scientific curiosity, collaboration, critical thinking, and inquiry. Moreover, application-level data were based on teacher self-reports, providing limited insight into actual classroom practices. Future studies should include student perspectives and observation-based methods to gain a more comprehensive understanding of students' cognitive and affective development.

Declaration of Interest

The authors declare no competing interest.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

References

Abegglen, S., Sinfield, S., & Burns, T. (Eds.). (2023). *Collaboration in higher education*. Bloomsbury Academic.

Adams, K. A., & McGuire, E. K. (2023). *Research methods, statistics, and applications*. Sage.

Akpan, B., Cavas, B., & Kennedy, T. (Eds.). (2023). *Contemporary issues in science and technology education*. Springer.

Antink-Meyer, A., Brown, M., & Wolfe, A. (2023). The scientific curiosity of preservice elementary teachers and confidence for teaching specific science topics. *Journal of Science Teacher Education, 34*(8), 883–902. https://doi.org/10.1080/1046560X.2023.2168858

Anupam, A. (2022). Teaching scientific inquiry as a situated practice: A framework for analyzing and designing science games. *Learning, Media and Technology, 47*(1), 125–142. https://doi.org/10.1080/17439884.2021.2020285

Bagdi, C., Read, K., & Serrano, S. (2024). *Scientific inquiry in social work*. Kruger Brentt.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice-Hall.

Bansal, G., & Ramnarain, U. (Eds.). (2023). *Inquiry-based science in the primary classroom*. Routledge.

Bastianens, E., Tilburg, J. V., & Merrienboer, J. V. (Eds.). (2017). *Research-based learning: Case studies from Maastricht University*. Springer.

Bjerknes, A. L., Wilhelmsen, T., & Foyn-Bruun, E. (2023). A systematic review of curiosity and wonder in natural science and early childhood education research. *Journal of Research in Childhood Education, 38*(1), 50–65. https://doi.org/10.1080/02568543.2023.2192249

Blair, G., Coppock, A., & Humphreys, M. (2023). *Research design in the social sciences: Declaration, diagnosis, and redesign*. Princeton University.

Book, N. (2024). *Critical thinking skills: Developing the ability to think critically and make informed decisions self growth short read*. Prabhat Prakashan.

Books, H. (2023). *Scientific inquiry: Using the methods of science in reasoning and investigation*. Heron Books.

Butcher, K. R., Hudson, M., Lane, M., & Larson, M. (2023). Critical thinking during science investigations: What do practicing teachers value and observe? *Teachers and Teaching, 29*(6), 594–614. https://doi.org/10.1080/13540602.2023.2191186

Chaparro-Banegas, N., Mas-Tur, A., & Roig-Tierno, N. (2024). Challenging critical thinking in education: New paradigms of artificial intelligence. *Cogent Education, 11*(1), Article 2437899. https://doi.org/10.1080/2331186X.2024.2437899

Chatfield, T. (2022). *Critical thinking: Your guide to effective argument, successful analysis, and independent study*. Sage.

Chen, J., Pan, L., Lu, Y., Zhang, T., Xu, D., Yan, S., & Ouyang, Z. (2023). Evolution of global scientific collaboration in mRNA vaccine research: Insights from bibliometric and social network analysis (2010~2023). *Human Vaccines & Immunotherapeutics, 19*(3), Article 2276624. https://doi.org/10.1080/21645515.2023.2276624

Chin, C., & Osborne, J. (2008). Students' questions: A potential resource for teaching and learning science. *Studies in Science Education, 44*(1), 1–39. https://doi.org/10.1080/03057260701828101

Cipresson, P., & Immekus, J. (Eds.). (2022). *Statistical guidelines: New developments in statistical methods and psychometric tools*. Frontiers.

Concannon, J. P., Brown, P. L., Lederman, N. G., & Lederman, J. S. (2020). Investigating the development of secondary students' views about scientific inquiry. *International Journal of Science Education, 42*(6), 906–933. https://doi.org/10.1080/09500693.2020.1742399

Cook, K., & Wheeler, W. (2023). Using popular fiction to inspire scientific inquiry. *Journal of College Science Teaching, 52*(5), 20–25. https://doi.org/10.1080/19434898.2023.12290244

Cottrell, S. (2023). *Critical thinking skills: Effective analysis, argument, and reflection*. Bloomsbury.

Crano, W. D., Brewer, M. B., & Lac, A. (2023). *Principles and methods of social research*. Routledge.

Creswell, J. W., & Guetterman, T. C. (2019). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Pearson.

Cry, J., & Goodman, S. W. (2024). *Doing good qualitative research*. Oxford.

Dave, A. (2024). *Science nexus bridging theory and practice*. Notion.

Dawson, V., & Venville, G. (Eds.). (2022). *The art of teaching primary school science*. Taylor & Francis.

De La Sienra, A. G. (2019). *A structuralist theory of economics*. Taylor & Francis.

Dehghanzadeh, H., Soltani Bahram, S., Noroozi, O., & Banihashem, S. K. (2024). Google Docs for improving students' collaborative scientific writing. *Innovations in Education and Teaching International*, 1–14. https://doi.org/10.1080/14703297.2024.2438345

DeMarrais, K., Roulston, K., & Coople, J. (2024). *Qualitative research design and methods: An introduction*. Myers Education.

Dos Santos, A., & Krause, J. (Eds.). (2017). *Science education research and new technologies*. IntechOpen.

Elder, L., & Paul, R. (2020). *Critical thinking: Learn the tools the best thinkers use*. Rowman & Littlefield.

Ennis, R. (1985). Goals for a critical thinking curriculum. In A. Costa (Ed.), *Developing minds* (pp. 54–57). Association for Supervision and Curriculum Development.

Fair, J. M. (2023). *Scientific collaboration strategies for successful research teams*. Johns Hopkins University.

Fan, J., Wu, H., & Ma, J. (2023). The impact of institutional difference on scientific collaboration: Empirical evidence from six provinces in central China. *Applied Economics Letters, 30*(17), 2488–2493. https://doi.org/10.1080/13504851.2023.2178617

Fasko, D., Jr., & Fair, F. (Eds.). (2020). *Critical thinking and reasoning: Theory, development, instruction, and assessment*. Brill.

Feldman, A., Alsultan, J., Laux, K., & Nation, M. (2024). *Dialogic collaborative action research in science education: Collaborative conversations for improving science teaching and learning*. Taylor & Francis.

Fetters, M. D. (2020). *The mixed methods research workbook: Activities for designing, implementing, and publishing projects*. Sage.

Finch, W. H. (2019). *Exploratory factor analysis*. Sage.

Forbes, C. (2022). *Academic libraries and collaborative research services*. Rowman & Littlefield.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Forman, J. (2020). *Critical thinking: An essential guide to improving your decision-making skills and problem-solving abilities along with avoiding logical fallacies and cognitive biases*. Amazon.

Fury, S. (2024). *How to think more effectively: The 5 best critical thinking models for problem solving*. SF Nonfiction.

Gai, L., Li, Y., Zheng, C., Wei, B., Jiang, Z., & Lederman, J. S. (2022). The progression of students' views about nature of scientific inquiry. *International Journal of Science Education, 44*(17), 2508–2540. https://doi.org/10.1080/09500693.2022.2138623

Garson, G. D. (2023). *Factor analysis and dimension reduction in R: A social scientist's toolkit*. Routledge.

Goodwin, B. (2020). *Building a curious school restores the joy that brought you to school*. Sage.

Greene, J. A., Sandoval, W. A., & Bråten, I. (Eds.). (2016). *Handbook of epistemic cognition*. Routledge.

Gunbayi, I. & Sorm, S. (2020). *Social paradigms in guiding management, social development, and social research.* Pegem Akademi

Gunbayi, I. (2023). Data analysis in qualitative research. *Journal of Action Qualitative & Mixed Methods Research, 2*(2), 1–10. https://doi.org/10.5281/zenodo.7763207

Guthrie, J. T., & Wigfield, A. (2000). *Engagement and motivation in reading*. Routledge.

Gwet, K. L. (2021). Large-sample variance of Fleiss generalized kappa. *Educational and Psychological Measurement, 81*(4), 781–790. https://doi.org/10.1177/0013164420973080

Gyllenpalm, J., Rundgren, C. J., Lederman, J., & Lederman, N. (2021). Views about scientific inquiry: A study of students' understanding of scientific inquiry in grade 7 and 12 in Sweden. *Scandinavian Journal of Educational Research, 66*(2), 336–354. https://doi.org/10.1080/00313831.2020.1869080

Haber, J. (2020). *Critical thinking*. MIT.

Hanscomb, S. (2023). *Critical thinking: The basics*. Taylor & Francis.

Hayes, A.F. (2018). *Introduction to mediation, moderation, and conditional process analysis.* Guilford.

Hiebert, J., Cai, J., Hwang, S., Morris, A. K., & Hohensee, C. (2023). *Doing research: A new researcher's guide*. Springer.

Hou, C., Fan, P., Du, D., Gui, Q., & Duan, D. (2020). Does international student mobility foster scientific collaboration? Evidence from a network analysis. *Compare: A Journal of Comparative and International Education, 52*(2), 327–344. https://doi.org/10.1080/03057925.2020.1765316

Hoyle, R. H. (Ed.). (2023). *Handbook of structural equation modeling*. Guilford.

Johnson, D. W., & Johnson, R. T. (1985). Relationships between Black and White students in intergroup cooperation and competition. *The Journal of Social Psychology, 125*(4), 421–428. https://doi.org/10.1080/00224545.1985.9713521

Johnson, R. B., & Christensen, L. (2020). *Educational research: Quantitative, qualitative, and mixed approaches*. Sage.

Judijanto, L., Rasyid, M. A., Fitriani, R., Faradini, Sabtu, R., Lestari, F. A., & Ihsan, I. (2025). *Science in elementary school: Approaches and methods for teaching science*. Mind Power.

Kan, Z., Tan, A. L., Pei, X., Wu, Q., & Yao, X. (2024). Exploring science teachers' epistemic beliefs about scientific inquiry and influencing factors. *International Journal of Science Education*, 1–24. https://doi.org/10.1080/09500693.2024.2428837

Kanyonga, L., Kafanabo, E. J., Chumba, S. K., & Kessio, D. K. (2024). Students' gender differences and scientific inquiry competencies in technical education and training institutions. *International Journal of Science Education*, 1–22. https://doi.org/10.1080/09500693.2024.2421465

Karwal, A., Kumar, R., & Sharma, R. (2023). *The power of curiosity in and beyond classrooms*. HarperCollins.

Keengwe, J. (Ed.). (2022). *Handbook of research on facilitating collaborative learning through digital content and learning technologies*. IGI.

Kenett, Y. N., Humphries, S., & Chatterjee, A. (2023). A thirst for knowledge: Grounding curiosity, creativity, and aesthetics in memory and reward neural systems. *Creativity Research Journal, 35*(3), 412–426. https://doi.org/10.1080/10400419.2023.2165748

Kirk, M., Tytler, R., & White, P. (2023). Critical thinking in primary science through a guided inquiry pedagogy: A semiotic perspective. *Teachers and Teaching, 29*(6), 615–637. https://doi.org/10.1080/13540602.2023.2191181

Kline, R. B. (2023). *Principles and practice of structural equation modeling*. Guilford.

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28*(2), 16–46. https://doi.org/10.3102/0013189X028002016

Lee, J. J., & Haupt, J. P. (2020). Scientific collaboration on COVID-19 amidst geopolitical tensions between the US and China. *The Journal of Higher Education, 92*(2), 303–329. https://doi.org/10.1080/00221546.2020.1827924

Li, L. (2023). Critical thinking from the ground up: Teachers' conceptions and practice in EFL classrooms. *Teachers and Teaching, 29*(6), 571–593. https://doi.org/10.1080/13540602.2023.2191182

Li, W., & He, C. (2022). Extensive dynamics of global collaboration network for scientific breakthroughs. *The Professional Geographer, 75*(4), 548–561. https://doi.org/10.1080/00330124.2022.2125881

Li, Z., Ji, S., Zhang, Y., Du, C., Chen, T., Liu, T., & Li, X. (2024). Associations among science study attitudes, habits, and science academic performance of elementary school students: A latent profile approach. *International Journal of Science Education*, 1–22. https://doi.org/10.1080/09500693.2024.2369725

Liao, W., & Yuan, R. (2024). Cultivating criticality through transformative critical thinking curriculums in a time of flux and transformation. *Educational Philosophy and Theory, 56*(8), 743–749. https://doi.org/10.1080/00131857.2024.2328076

Liu, X. (2020). *Using and developing measurement instruments in science education: A Rasch modeling approach*. Information Age.

Luhanga, U., & Harbaugh, A. G. (Eds.). (2021). *Basic elements of survey research in education: Addressing the problems your advisor never told you about*. Information Age.

Madison, E. (2023). *Raising empowered learners cultivating students' curiosity, character, and confidence*. Rowman & Littlefield.

Mahat, D., & Kandel, D. R. (2023). *Scientific research methodologies and techniques*. AG.

Marco, P. D. (2025). *Reasoning and proof: Unraveling the mysteries of scientific inquiry*. Pasquale De Marco.

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

McPhee, R., & Cox, D. (2024). Intellectual autonomy as the aim of critical thinking. *Educational Philosophy and Theory, 57*(2), 186–196. https://doi.org/10.1080/00131857.2024.2412759

Mercer, N., & Littleton, K. (2007). *Dialogue and the development of children's thinking: A sociocultural approach*. Routledge.

Mertens, D. M. (2023). *Mixed methods research*. Bloomsbury Academic.

Meyer, D. K., Turner, J. C., & Perry, N. E. (2024). *Classroom research partnerships: Collaborating with school communities for the common good*. Routledge.

Mindrila, D. (Ed.). (2017). *Exploratory factor analysis applications in school improvement research*. Nova.

Muchie, M., Baskaran, A., & Tang, M. (Eds.). (2024). *China-Africa science, technology and innovation collaboration*. Springer.

Nahar, L., & Tayem, N. (2024). *Cases on collaborative experiential ecological literacy for education*. IGI.

Newsom, J. T. (2023). *Longitudinal structural equation modeling: A comprehensive introduction*. Taylor & Francis.

Nicolopoulou, A., Barandone, A. C., Vosniadou, S., & Osterhaus, C. (Eds.). (2021). *The emergence and development of scientific thinking during the early years: Basic processes and supportive contexts*. Frontiers.

Ninos, G. (2023). Rethinking dialectic in the 21st century: Interpretation, method and scientific inquiry. *Critique, 51*(2–3), 363–379. https://doi.org/10.1080/03017605.2023.2292856

Oberman, R. (2023). Creativity, curiosity and catharsis: Positive emotions in climate change education through picture books. *Environmental Education Research, 30*(11), 2031–2056. https://doi.org/10.1080/13504622.2023.2286940

Okoko, J. M., Tunison, S., & Walker, K. D. (2023). *Varieties of qualitative research methods: Selected contextual perspectives*. Springer.

Orona, G. A., & Pritchard, D. (2021). Inculcating curiosity: Pilot results of an online module to enhance undergraduate intellectual virtue. *Assessment & Evaluation in Higher Education, 47*(3), 375–389. https://doi.org/10.1080/02602938.2021.1919988

Paavola, S., & Shook, J. R. (Eds.). (2021). *Abduction in cognition and action: Logical reasoning, scientific inquiry, and social practice*. Springer.

Paul, R., & Elder, L. (2020). *Critical thinking tools for taking charge of your professional and personal life*. Rowman & Littlefield.

Paul, R., & Elder, L. (2006). Critical thinking: The nature of critical and creative thought. *Journal of Developmental Education, 30*(2), 34–35.

Pollarolo, E., Størksen, I., Skarstein, T. H., & Kucirkova, N. (2022). Children's critical thinking skills: Perceptions of Norwegian early childhood educators. *European Early Childhood Education Research Journal, 31*(2), 259–271. https://doi.org/10.1080/1350293X.2022.2081349

Pu, S., & Xu, H. (2023). Curriculum and the cultivation of critical thinking: A critical realist conception. *Educational Philosophy and Theory, 56*(8), 750–760. https://doi.org/10.1080/00131857.2023.2227380

Pu, Y. A., & Barnard, R. (2025). *Teacher and learner agency for collaborative learning: Academic writing in a blended environment*. Taylor & Francis.

Recker, J. (2021). *Scientific research in information systems: A beginner's guide*. Springer.

Reed, I. K. G., Kraczkowski, M. L., & Pearlman, S. J. (2024). Developing critical thinking in biology through progressive writing assignments. *Journal of College Science Teaching, 53*(6), 563–572. https://doi.org/10.1080/0047231X.2024.2390298

Ribosa, J., & Duran, D. (2022). Students creating videos for learning by teaching from their scientific curiosity. *Research in Science & Technological Education, 42*(2), 237–254. https://doi.org/10.1080/02635143.2022.2116419

Rogante, M., Lebedev, V. T., Kulvelis, Y., Vul, A. Ya., Kozlov, V. S., & Konoplev, K. A. (2021). The 20-year Russian-Italian scientific collaboration in industrial applications of neutrons and prospects on high flux reactor "PIK" of Russian National Centre "Kurchatov Institute." *Neutron News, 32*(3), 9–15. https://doi.org/10.1080/10448632.2021.1946342

Roos, J. M., & Bauldry, S. (2021). *Confirmatory factor analysis*. Sage.

Rousseau, D. L., & van Gelder, T. (2024). Teaching critical thinking with argument mapping. *Journal of Political Science Education*, 1–17. https://doi.org/10.1080/15512169.2024.2388821

Salmons, J. (2019). *Learning to collaborate, collaborating to learn: Engaging students in the classroom and online*. Taylor & Francis.

Schwab, J. J. (1962). The teaching of science as inquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3–103). Harvard University.

Schwarz, T. A., Nikendei, C., Cranz, A., Friederich, H. C., & Bugaj, T. J. (2023). An untapped potential: Curiosity in medical school. *Medical Teacher, 46*(7), 939–947. https://doi.org/10.1080/0142159X.2023.2288546

Senent, I. G., Kelley, K., & Abo-Zena, M. M. (2021). Sustaining curiosity: Reggio-Emilia inspired learning. *Early Child Development and Care, 191*(7–8), 1247–1258. https://doi.org/10.1080/03004430.2021.1900835

Shahriary, E., Gill, T. E., & Langford, R. P. (2020). Bibliometric analysis of piosphere research: Implications for conservation and scientific collaboration. *International Journal of Sustainable Development & World Ecology, 28*(4), 316–325. https://doi.org/10.1080/13504509.2020.1821256

Shearmur, J. (Ed.). (2020). *A sceptical theory of scientific inquiry: Problems and their progress*. Brill.

Shellito, C. (2020). Student-constructed weather instruments facilitate scientific inquiry. *Journal of College Science Teaching, 49*(3), 10–15. https://doi.org/10.2505/4/jcst20_049_03_10

Singh, S., Tiwari, P. S., Chauhan, N. K. S., & Verma, B. (2023). *Scientific research methodologies*. AG.

Sorgente, A., Claxton, S. E., Schxab, J. R., & Vasylis, R. (Eds.). (2025). *Flourishing as a scholar: Research methods for the study of emerging adulthood*. Oxford.

Su, Y., Long, C., Yu, Q., Zhang, J., Wu, D., & Duan, Z. (2017). Global scientific collaboration in COPD research. *International Journal of Chronic Obstructive Pulmonary Disease, 12*, 215–225. https://doi.org/10.2147/COPD.S124051

Suwono, H., Rofi'Ah, N. L., Saefi, M., & Fachrunnisa, R. (2021). Interactive socio-scientific inquiry for promoting scientific literacy, enhancing biological knowledge, and developing critical thinking. *Journal of Biological Education, 57*(5), 944–959. https://doi.org/10.1080/00219266.2021.2006270

https://doi.org/10.33225/jbse/25.24.802

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Sweller, J. (2009). What human cognitive architecture tells us about constructivism. In S. Tobias & T. M. Duffy (Eds.), *Constructivist instruction: Success or failure?* (pp. 127–143). Routledge.
Tashakkori, A., Johnson, R. B., & Teddlie, C. (2020). *Foundations of mixed methods research*. Sage.
Varlık, S. (2024). Critical and creative thinking in science teachers: The moderating role of epistemology. *Journal of Baltic Science Education*, *23*(5), 964–978. https://doi.org/10.33225/jbse/24.23.964
Varlık, S., Varlık, F., & Karakuş, M. (2024). Is creative thinking and innovation in teachers enough on their own? What happens if there is no entrepreneurship and reflective thinking? *Teaching and Teacher Education*, *152*, 104800. https://doi.org/10.1016/j.tate.2024.104800
Verma, J. P., & Verma, P. (2024). *Understanding structural equation modeling: A manual for researchers*. Springer.
Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University.
Whitworth, B. A. (2025). Fostering innovation, creativity, and curiosity in science education. *The Science Teacher, 92*(3), 6–7. https://doi.org/10.1080/00368555.2025.2491937
Willis, J., & Willis, M. (2020). *Research-based strategies to ignite student learning insights from neuroscience and the classroom*. ASCD.
Wulff, K. (2022). *Regulation of scientific inquiry: Societal concerns with research*. Taylor & Francis.
Zou, P. X. W., & Xu, X. (2023). *Research methodology and strategy*. Wiley.

Received: *July 23, 2025* Revised: *August 26, 2025* Accepted: *September 02, 2025*

Cite as: Baba Kaya, H., Akpınar, S., Çilek, A., Gürer, G. T., Akpınar, Ö., Görünü, R. M., & Varlık, S. (2025). Scientific curiosity and critical thinking through scientific collaboration: The moderated mediation role of scientific inquiry. *Journal of Baltic Science Education*, *24*(5), 802–823. https://doi.org/10.33225/jbse/25.24.800

Hande Baba Kaya PhD, Associate Professor, Düzce University, Düzce, Türkiye.
E-mail: handebabakaya@duzce.edu.tr
ORCID: https://orcid.org/0000-0002-9281-2588

Selahattin Akpınar PhD, Professor, Düzce University, Düzce, Türkiye.
E-mail: selahattinakpinar@duzce.edu.tr
ORCID: https://orcid.org/0000-0002-1676-4465

Adem Çilek, PhD, Associate Professor, Çankırı Karatekin University, Çankırı, Türkiye.
E-mail: ademcilek@karatekin.edu.tr
ORCID: https://orcid.org/0000-0003-1295-6520

Gülten Türkan Gürer PhD, Gazi University, Ankara, Türkiye.
E-mail: gulten.gurer@gmail.com
ORCID: https://orcid.org/0000-0002-8054-6489

Öznur Akpınar PhD, Associate Professor, Karamanoğlu Mehmet Bey University, Karaman, Türkiye.
E-mail: oznurakpinar@kmu.edu.tr
ORCID: https://orcid.org/0000-0002-8775-8724

Recep Mehmet Görünü PhD Student, Düzce University, Düzce, Türkiye.
E-mail: recepmehmetgorunu@duzce.edu.tr
ORCID: https://orcid.org/0009-0006-1427-0820

Savaş Varlık *(Corresponding author)* PhD, Head Teacher, Ministry of National Education of the Republic of Türkiye, Ankara, Türkiye.
E-mail: savasvarlik@yahoo.com
ORCID: https://orcid.org/0000-0001-8894-2649